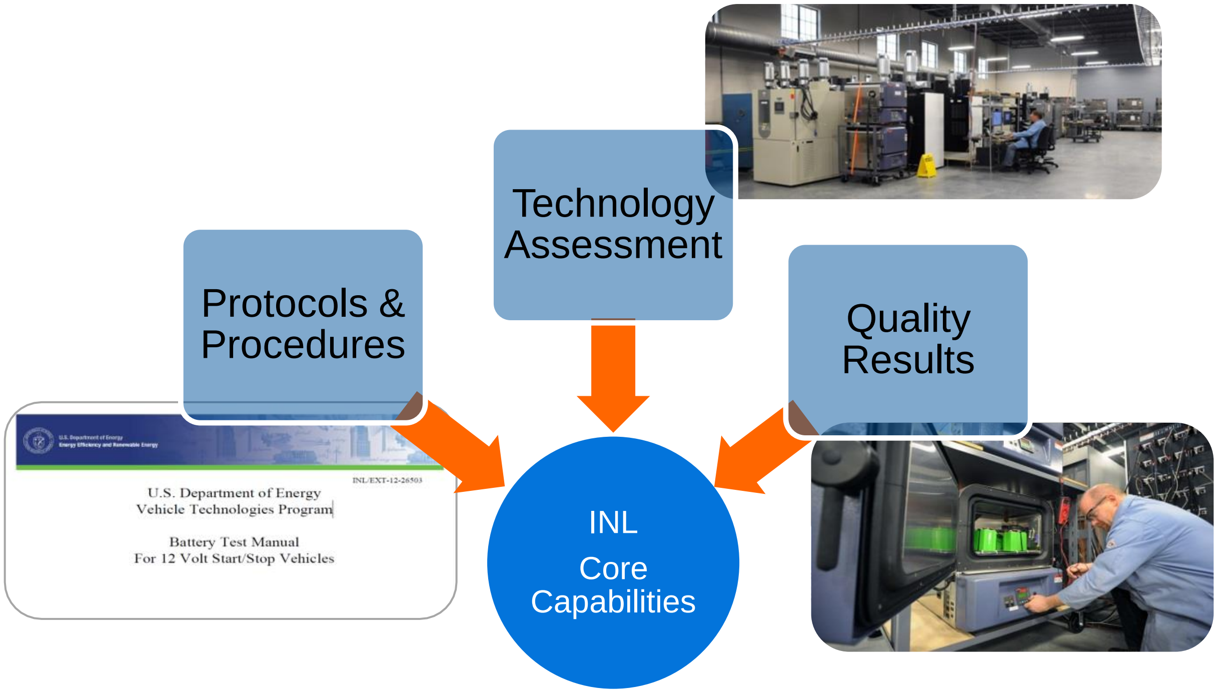
Effects of Fast Charging on EV Battery Life and Vehicle Performance



Matt Shirk

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Idaho National Laboratory

Presentation Outline

- Project Description
- Testing Methodology
- Characteristics of Vehicle Response
- Results of Vehicle and System Testing
- Laboratory Cycling and Testing
- Continuing Work
- Future Work
- Acknowledgments

Overall Project Description

Drive BEVs and charge exclusively with DC Fast Charging or AC Level 2 Charging under the following conditions:

- Hot climate
- Passive pack cooling architecture
- Frequent charging (2x daily)
  - OEM recommends a max of 1x daily

Determine the effects of exclusive DC Fast Charging, relative to AC Level 2 Charging on:

- Battery capacity and power capability degradation
- Resulting vehicle performance changes
- Thermal response of battery

Results intended to reflect extreme usage case, and to support development of future in-lab testing of more battery types

Overall Project Description - Continued

Project Plan

- Baseline test four 2012 Nissan Leaf EVs at a closed test track when new
- Baseline test the batteries of each vehicle in the laboratory
- Accumulate nearly identical on-road mileage Charge two only with ACL2 EVSE, and two only with a DCFC
- Log on-road driving and charging data continuously
- Repeat laboratory battery tests at 10k mile intervals
- Repeat track testing after 50k miles
- Compare testing results from DCFC charged vehicles to those from ACL2 charged vehicles

Driving and Charging Methods

Driving

- Each vehicle driven twice per day, morning and evening
- Vehicles driven in alternating pairs of 1 DCFC Car and 1 ACL2 Car
- Fixed Route, Highway, City
- City driving close to base
- Return to base when range indicated at 5 mi

Charging

- Two vehicles charged exclusively by 50kW DCFC
- Two vehicles charged elusively by 3.3kW ACL2
- Charging immediately following driving

On-Road Driving and Charging Data Collection Methods

CAN Data Logging – 1 HZ

Driving
- Vehicle Speed
- Battery Temperature (avg. of 4 sensors in pack)
- Battery Current and Voltage
- State of Charge
- Ambient Temperature Sensor

Charging
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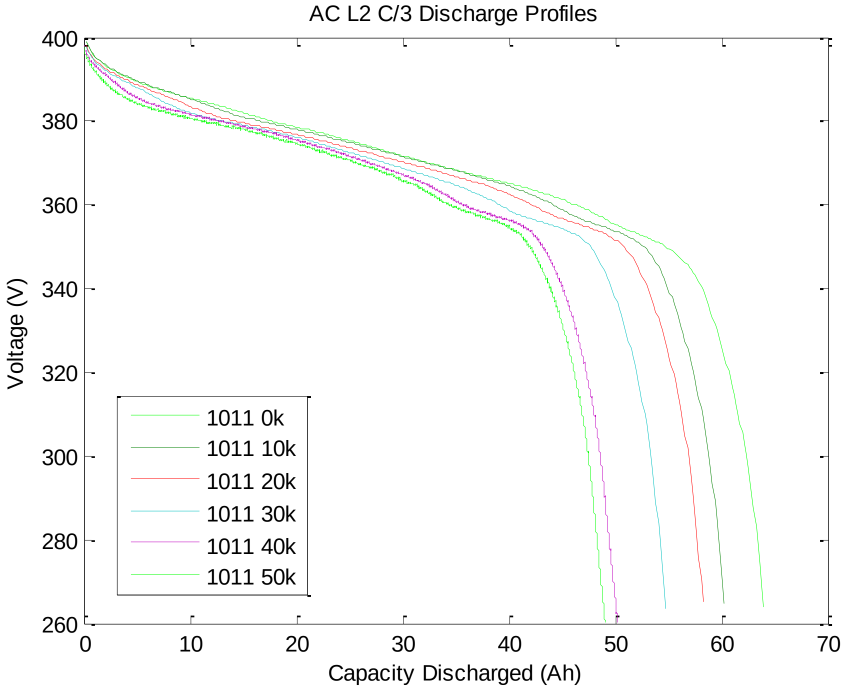
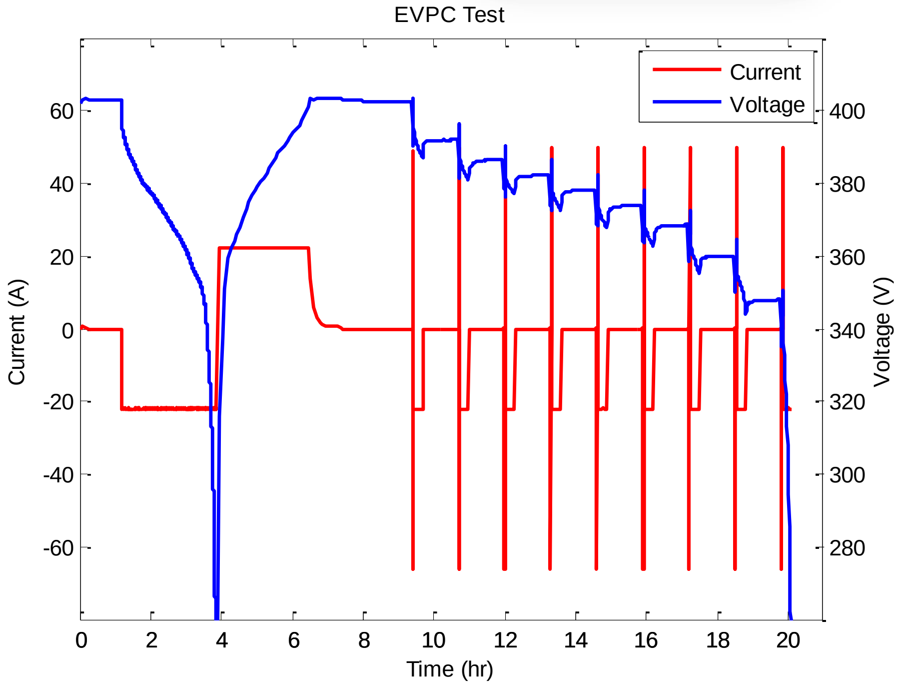
Laboratory Battery Testing Methods

Battery packs were removed and tested with a Bitrode FTF Cycler at Baseline and every 10k miles

- C/3 (22.07A) Constant Current Discharge Capacity
  - Ah & Wh available between Vmax and Vmin
- Electric Vehicle Power Characterization Test
  - Internal resistance, power capability





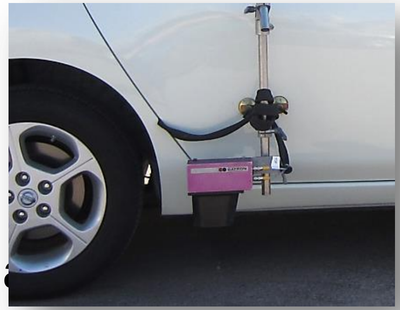
Track Testing Methods

Vehicles tested on closed test tracks for acceleration and constant speed range

- Energy, Speed, Distance measured with calibrated instrumentation
- Vehicles all charged to completion with ACL2 EVSE prior to track tests

- 0-60 MPH Acceleration Testing
  - Measure peak power drawn during accel runs
  - Measure several runs in each straight-away direction

- Constant Speed Range Test
  - Accelerate up to 45 MPH, maintain
  - Test complete when vehicle cannot be maintained at or



Driving Characteristics

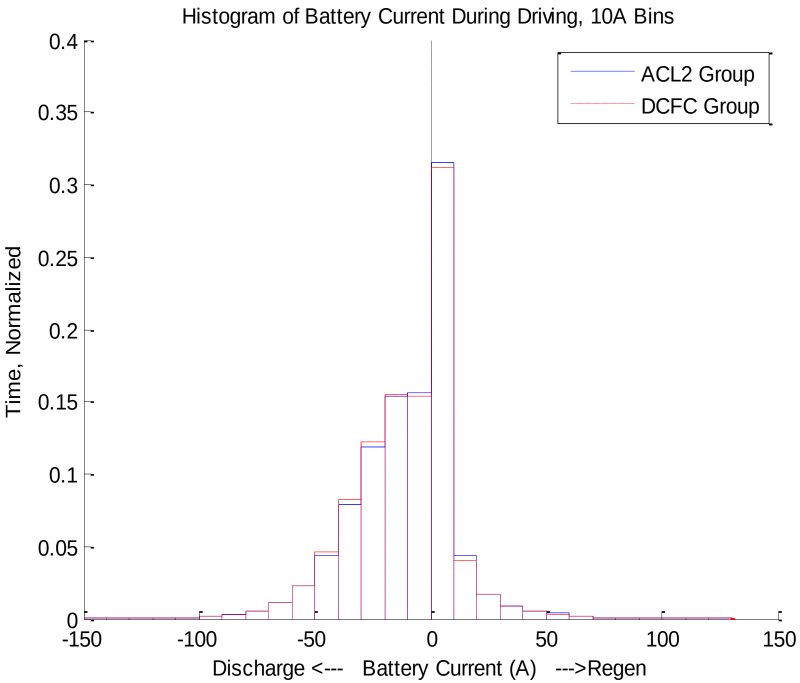
All battery packs were cycled very similarly during driving

- Charge drawn from and regenerated to battery binned by current magnitude

- Small Variation
  - Among cars
  - Between ACL2, DCFC groups

- Energy/Distance tightly grouped
  - Driving in pairs
  - Rotating drivers
  - Auto 72 climate control

Group	ACL2	ACL2	DCFC	DCFC
Vehicle Number	1011	4582	2078	2183
Energy Consumption (DC Wh/mi)	225	229	231	229

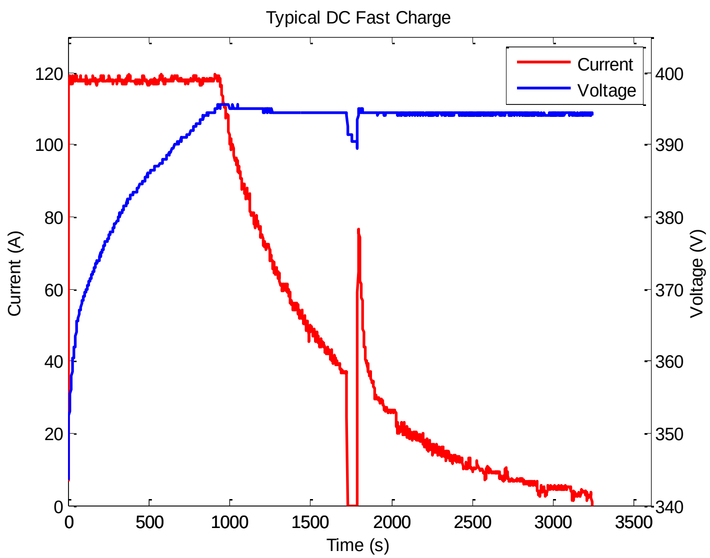


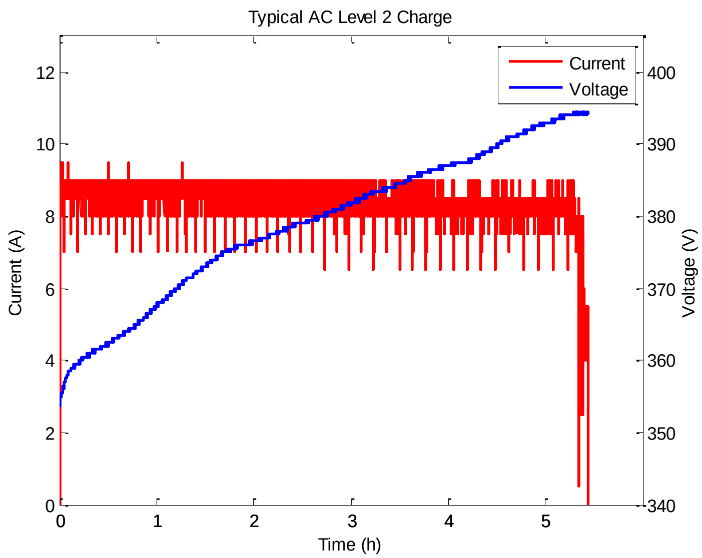
Charging Characteristics

DC Fast Charge

- 120 A max DC current, ~50 kW
- Charge always restarted once
- CV taper charge around 395 V
- Typical charge stop around 1A
- <1 hour for full charge

- AC Level 2 Charge
  - 9 A max current, ~3.3 kW
  - Short CV period
  - 5-6 hour charge

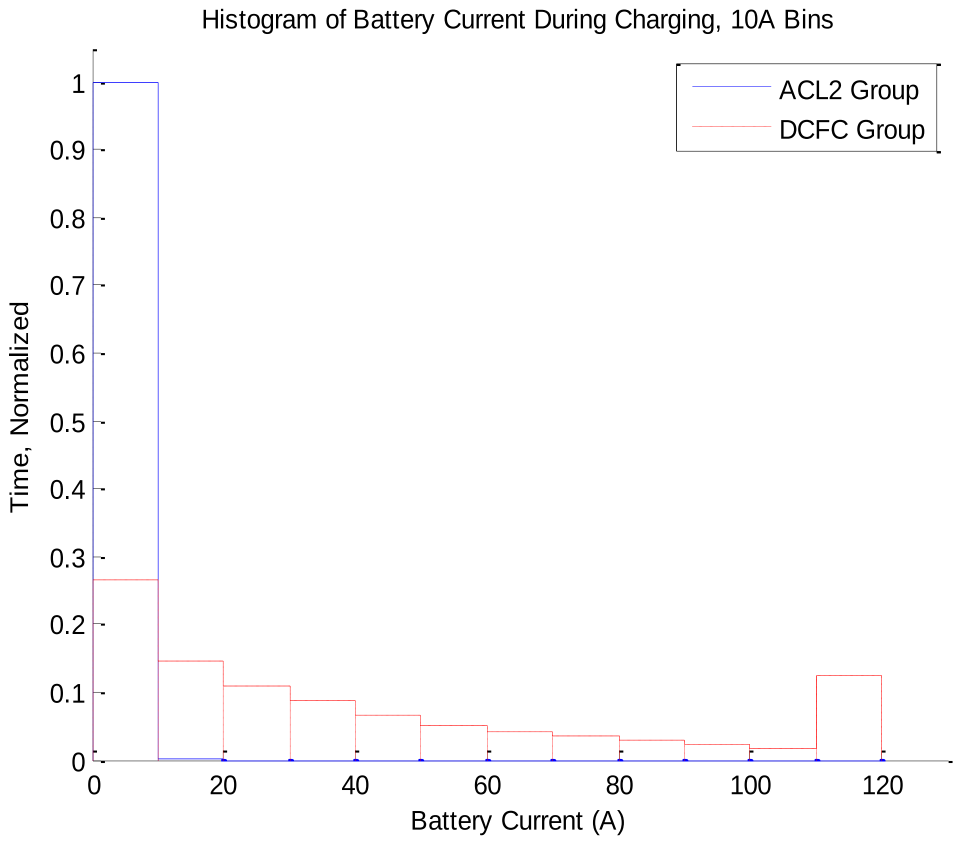




Charging Current Characteristics

Percent of Charge Time Binned by Charge Current

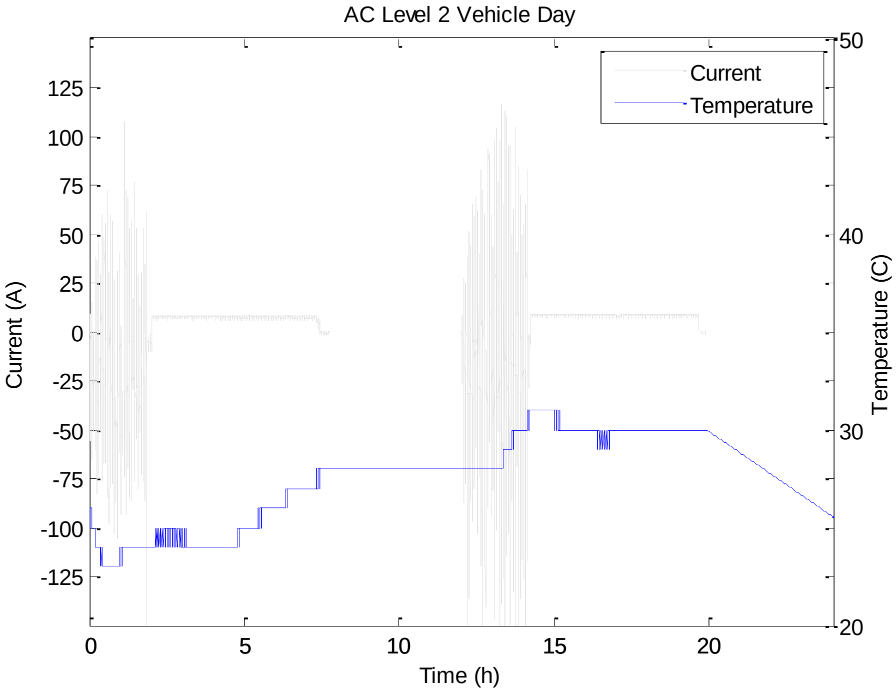
- ACL2 charging almost all less than 10A
- DCFC charging distributed due to long taper charge

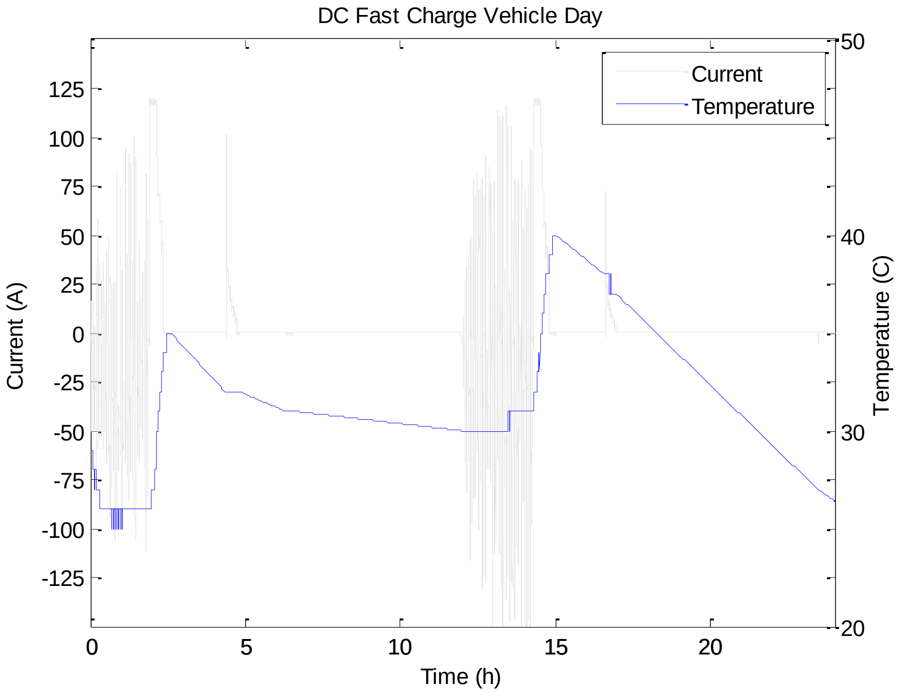


Daily Cycling and Thermal Response

One test day is shown for an ACL2 car and a DCFC car

- The same day is shown for each
- Pack temperature rise is prominent during high current part of DCFC
- Pack Temperature logged during driving and charging
  - Linear interpolation between logged data – imperfect but approximate

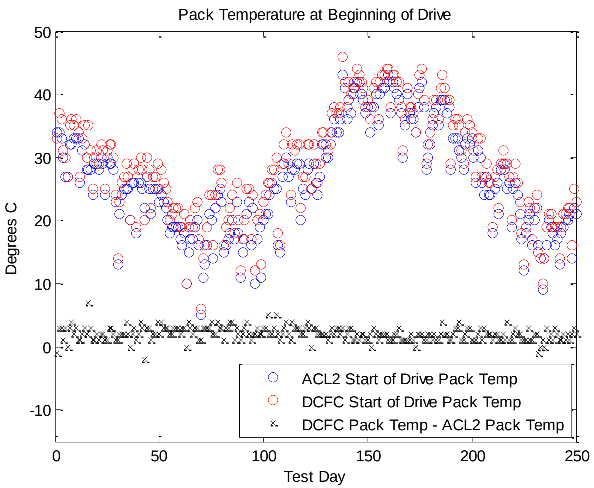


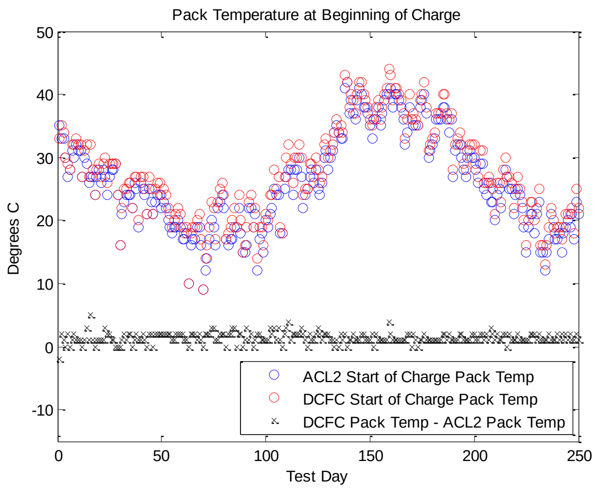


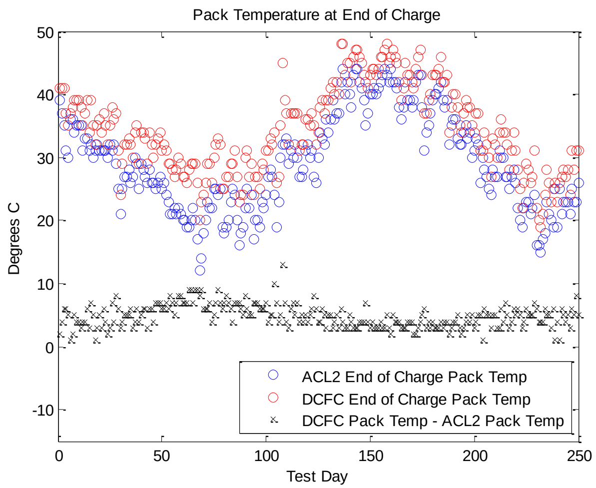
Battery Temperature

Differences in battery temperature between ACL2 and DCFC charged cars are shown at different times of the day for 250 days

- The longest soak is between end-of-charge and start-of-drive
- Seasonal temperature variation dominates pack temperatures
- Smallest mean of difference observed at end-of-drive/beginning-of-charge
- Largest mean of difference observed at end-of-charge, charge rate difference forcing temperature difference



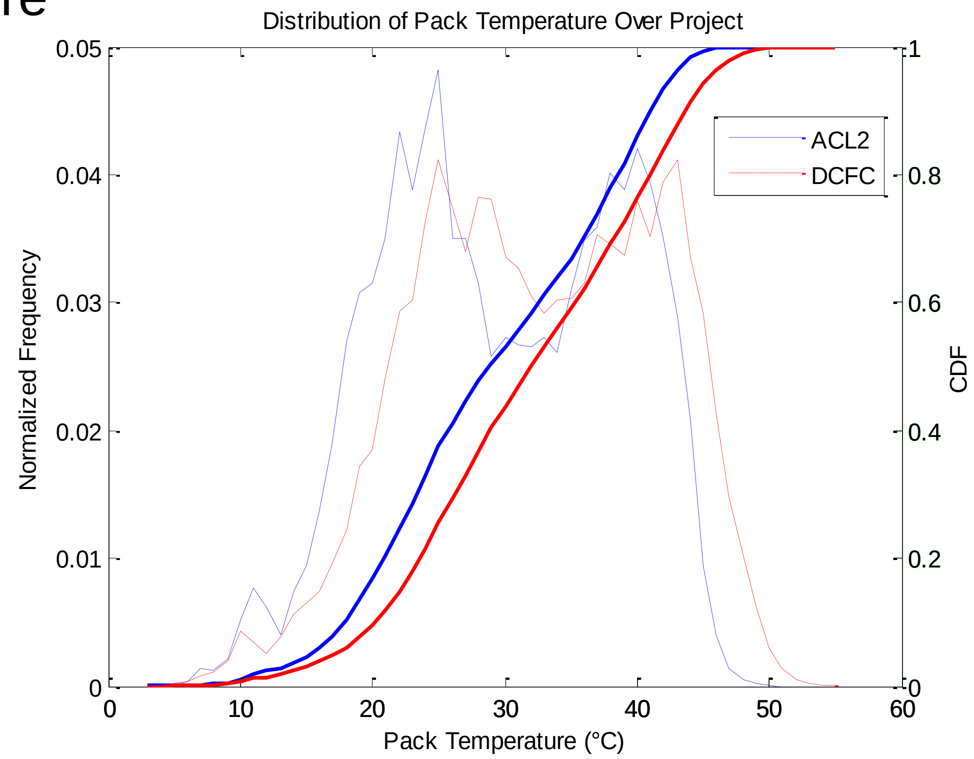




Pack Temperature Over 50k Miles

Histogram and CDF of Time Spent At Temperature for both Packs

- Same distribution shape, with a few degrees shift hotter for DCFC packs
- Cumulative distribution shows percent of time spent over/under given temperature

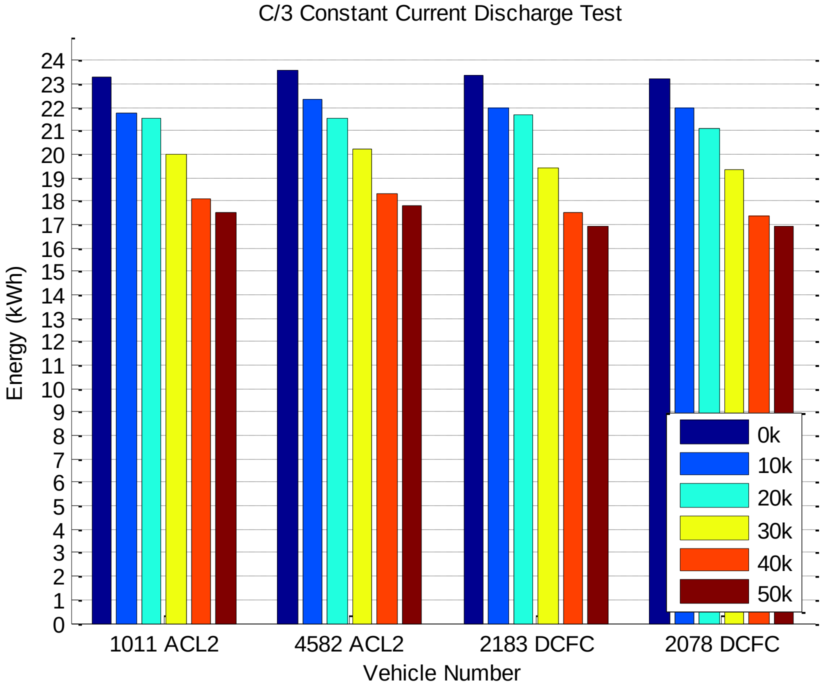


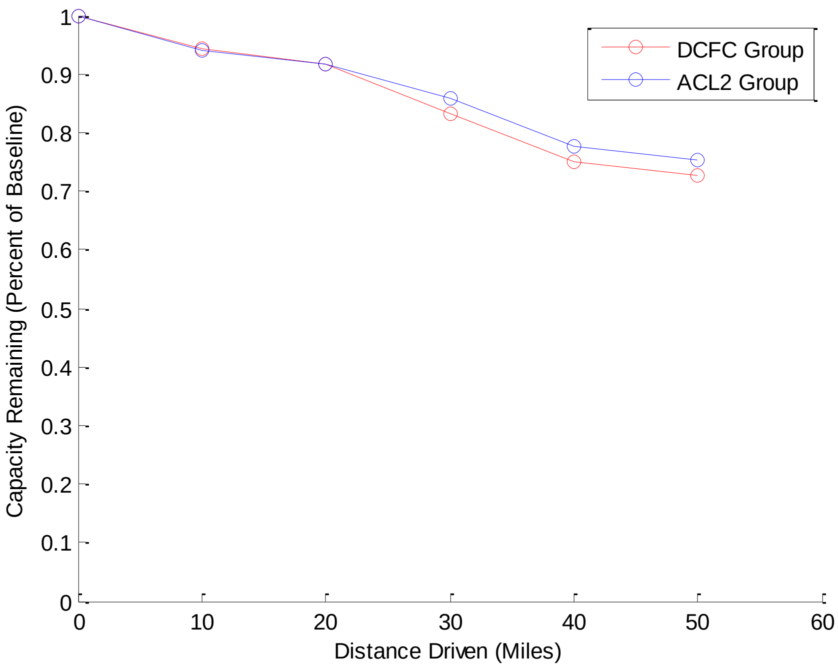
Laboratory Battery Capacity Testing

3-Hour Energy Capacity at 10k mile intervals

- Each vehicle, bar chart
- Average of each group, line chart

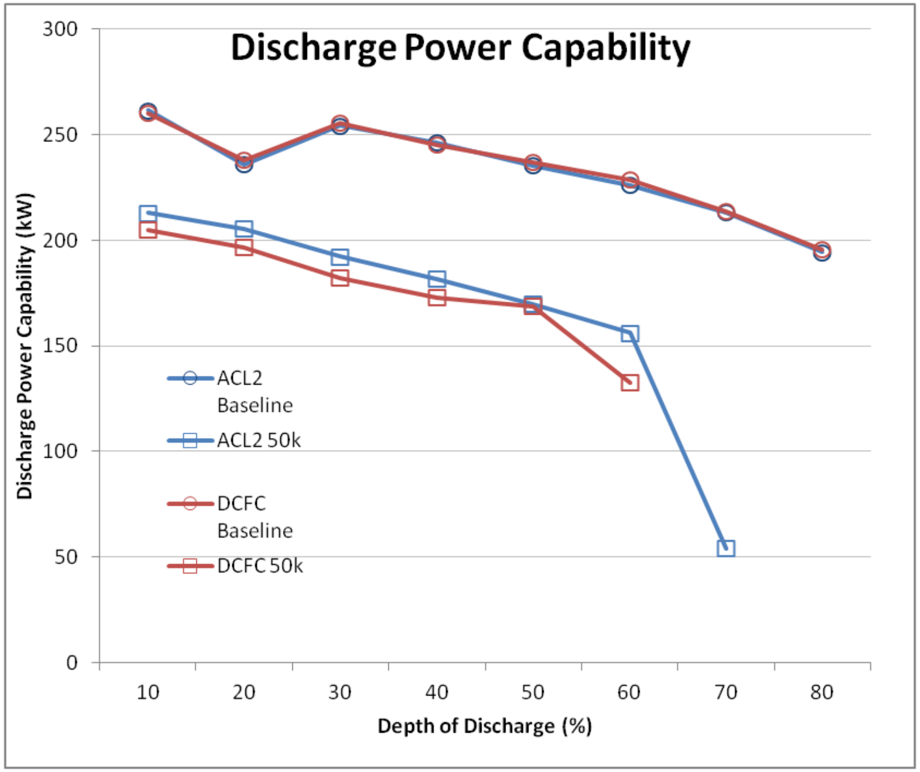
Difference in capacity change between charge type groups is small compared to overall capacity loss





Laboratory Battery Power Testing

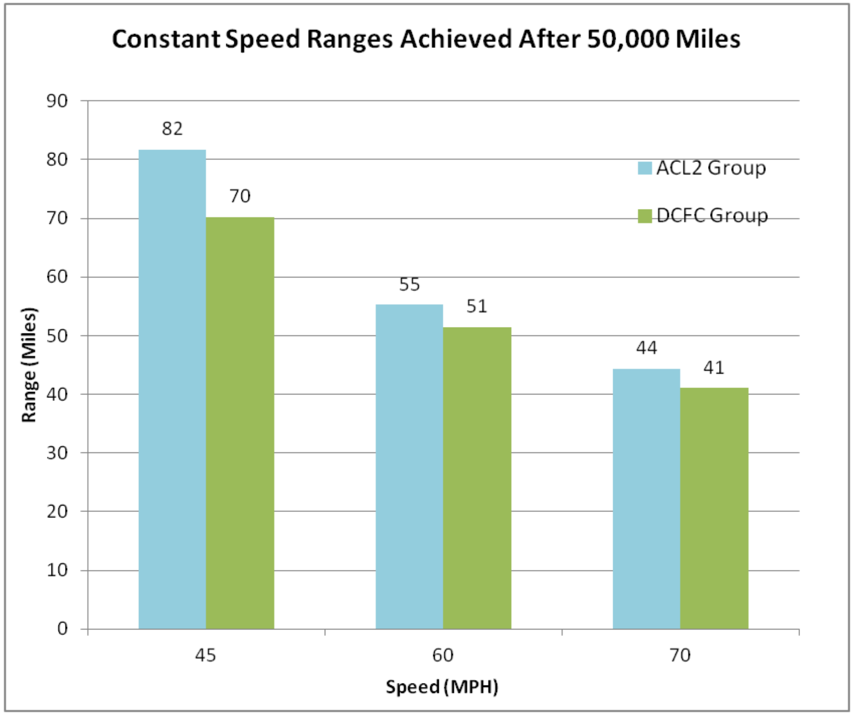
Changes in Power Capability and Internal Resistance
- DCFC power capability slightly less than ACL2 at 50k, though this difference is small compared to change from baseline
- Difference in IR growth between groups smaller than precision of tests

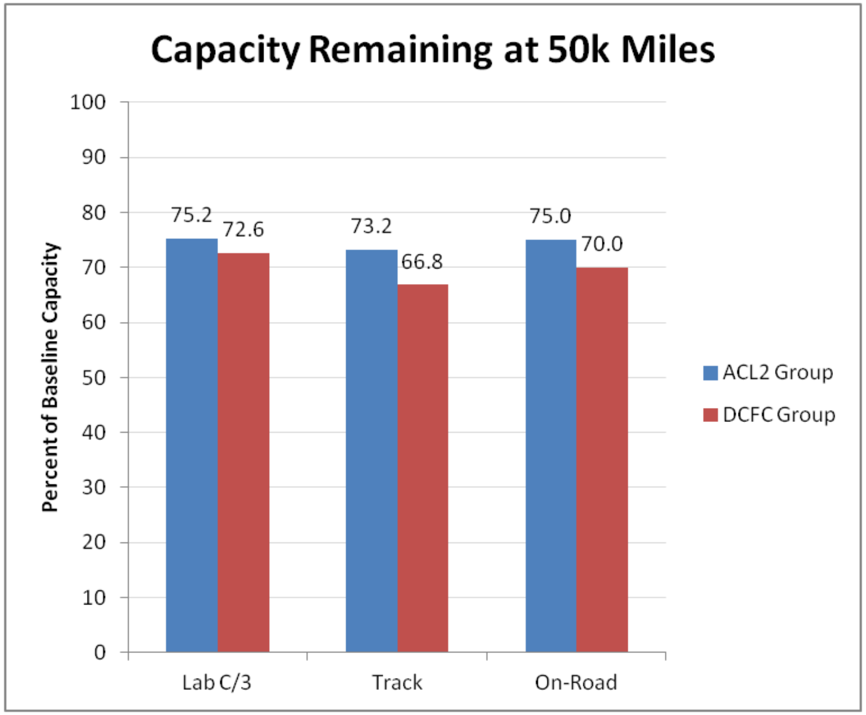


Range Testing Results

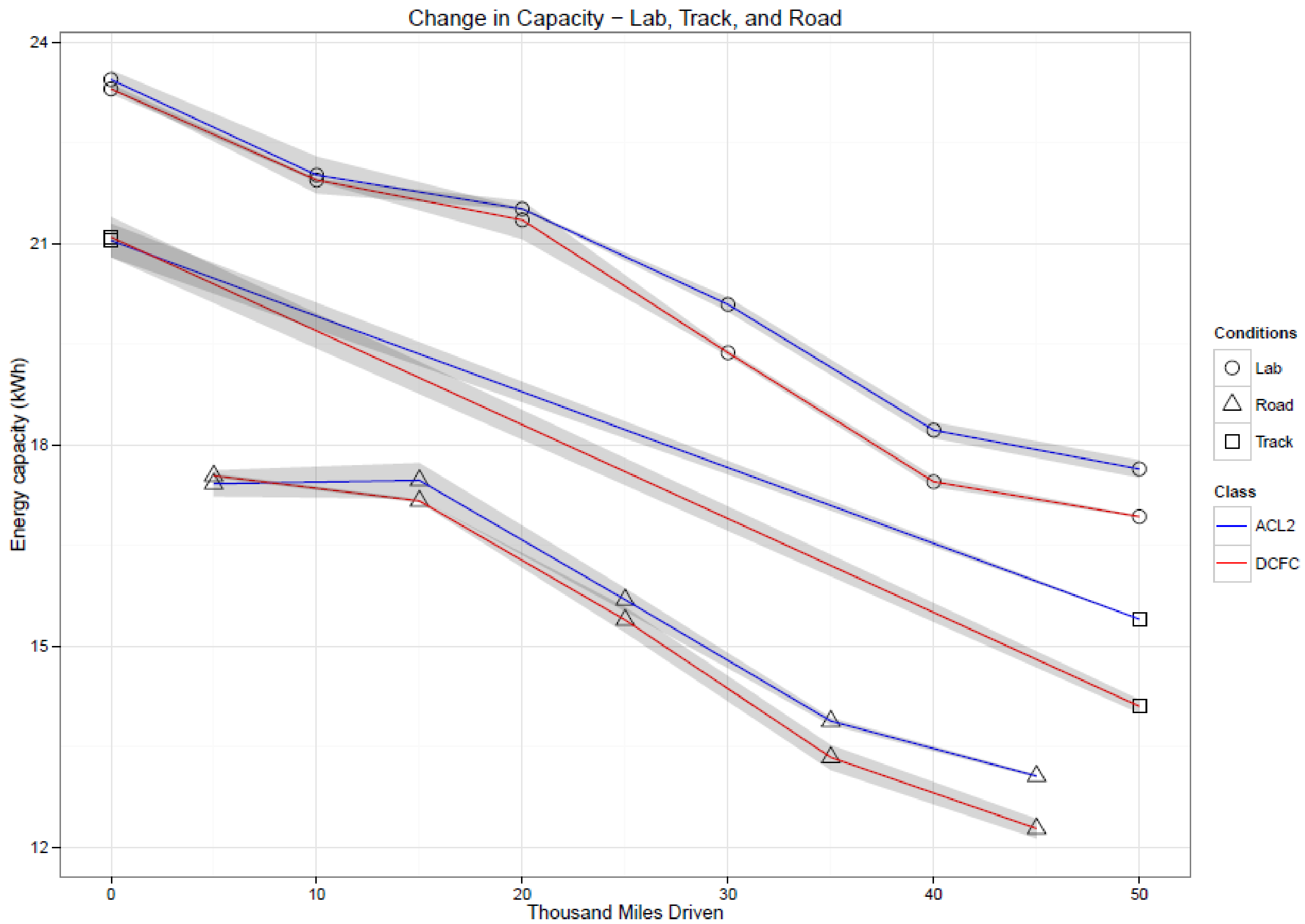
Difference in Range

- DCFC group avg. 85% to 93% of ACL2 range at 50k
- Range impact between groups is more apparent than laboratory capacity results. Energy discharged during tests can be compared.
  - Track and on-road: battery management system determination





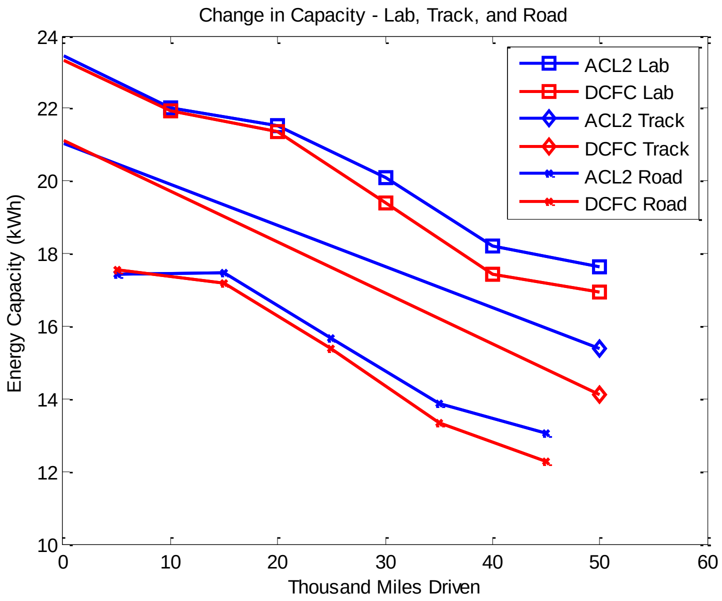
Battery Capacity Remaining – 3 Methods



Battery Capacity Loss

Capacity Loss Shown 3 Ways

- Dominated by ambient conditions, degree varies among test periods
  - Cycles at ambient temperature primary capacity loss driver
  - DCFC secondary – investigate mechanisms in future work
- Capacity loss rate non-linear given fixed thermal conditions
  - Lab based constant temp cycling shows capacity loss rate slows from initial, approaches steady after approximately ~15k miles (250 cycles) at 30°C



Group	ACL2	ACL2	DCFC	DCFC
Vehicle number	**1011**	**4582**	**2078**	**2183**
0-10k Miles (Oct-Jan)	28.6	28.6	32.5	32.7
10-20k Miles (Jan-Mar)	22.7	22.5	27.6	27.6
20-30k Miles (Apr-Jul)	35.7	36.0	39.8	39.8
30-40k Miles (Jul-Oct)	38.2	38.4	40.8	40.8
40-50k Miles (Oct-Mar)	23.2	23.6	27.3	27.3

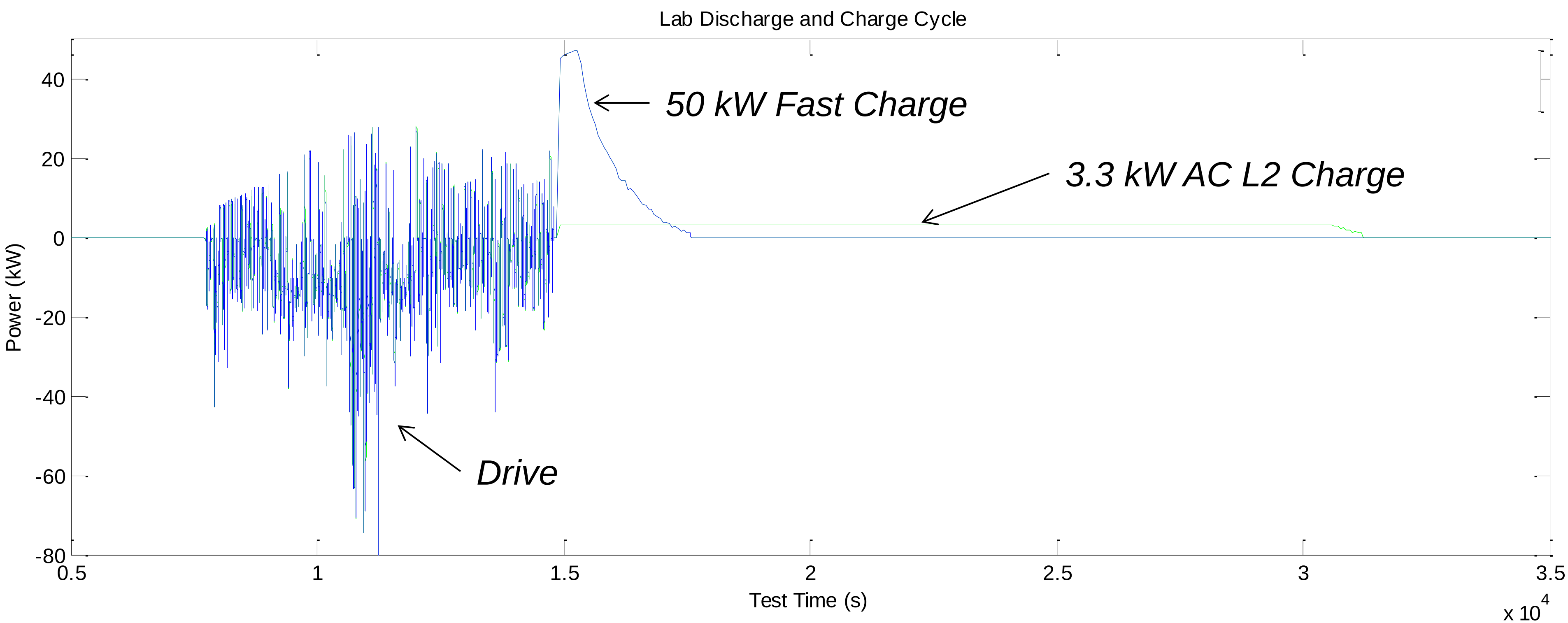
Laboratory Cycling and Testing

Constant Temperature Pack Testing

- Identical power-time discharge cycles for 50k miles
- Charge at AC L2, DCFC Rates, one pack each
  - Remove seasonal variation – Constant 30ºC Ambient
- More frequent capacity and power testing – every 30 days
- Compare on-road results to in-lab results, publication planned pending completion of laboratory pack cycling

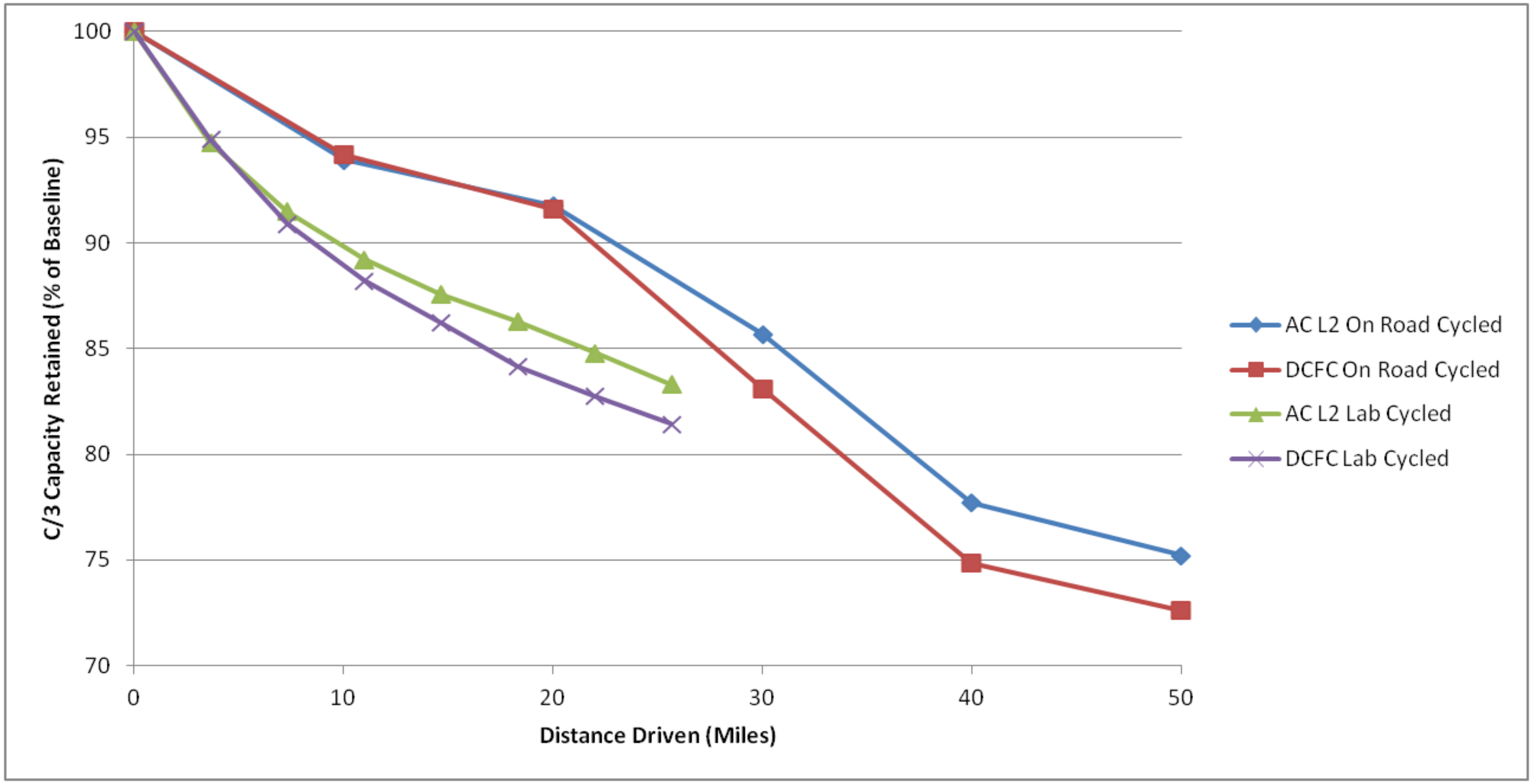
Lab Cycling – Drive Cycle

- Identical discharge power trace for each pack
- Blue – DC Fast Charged power trace
- Green – AC L2 Charged power trace



Lab Cycling – Results-to-Date

- On-Road cycled packs subjected to varying temperatures each period
- In-Lab Cycled packs cycled in constant ambient temp (30° C)
- Capacity loss rate approaches steady state in constant temp testing



Future Work

Cell or Module level testing

- More conditions, less cost
- Testing methods based on results of this project
- Other cell chemistries can be tested for fraction of cost of full-pack testing
- AVTA On-road testing can provide thermal conditions for a variety of different vehicles/packs

Acknowledgement

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